OBSERVATION OPTICAL SYSTEM AND OBSERVATION DEVICE

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to an observation optical system used for an observation device having an antivibration function, such as a telescope or binocular.

Related Background Art

As an observation optical system for an observation device such as a telescope or binocular, an observation optical system having an antivibration function is disclosed in, for example, Japanese Patent Application Laid-Open No. 10-186228.

This observation optical system has an objective optical system having a first lens unit with a positive power (the reciprocal of the focal length) and a second lens unit with a negative power arranged from the object side in the order named, and the second lens unit is driven in a direction perpendicular to the optical axis to effect the antivibration function.

The above objective optical system has a so-called telephoto type arrangement, which is characterized in that the total length of the objective optical system can be shortened.

In the observation optical system, however, an

image inverting system such as an image inverting prism must be placed between the objective optical system and the eyepiece optical system, and a driving mechanism for antivibration must be placed inside the objective optical system. Since they require a certain space, the merit of shortening the optical system by making the objective optical system into a telephoto type system is low.

In this case, in driving the second lens unit of the two-unit optical system to effect the antivibration function, an antivibration sensitivity Si is expressed by the following equation using a magnification β of the second lens unit:

$$Si = (1 - \beta)$$

In the arrangement having positive and negative lens units arranged from the object side in the order named, since $\beta > 1$, and hence in order to realize $|Si| > 1$, $\beta > 2$ needs to be set. This arrangement is not so advantageous in terms of sensitivity. An increase in sensitivity can be attained by increasing β of the second lens unit. However, since the power ratio between the positive and negative lens units excessively increases, many lenses are required for aberration correction.

The arrangement disclosed in Japanese Patent Application Laid-Open No. 2000-352664 (corresponding to USP 6,249,380B1) has an objective lens system

having a first lens unit with a positive power and a second lens unit with a positive power arranged from the object side in the order named. The second lens unit is driven in a direction perpendicular to the optical system to effect an antivibration function.

The total length of this objective optical system is longer than the focal length of the objective optical system. This makes it possible to ensure a space for an image inverting prism and the like. In addition, a space for an antivibration driving mechanism can be easily ensured.

In the arrangement disclosed in Japanese Patent Application Laid-Open No. 2000-352664, however, the magnification β of the second lens unit falls within the range of $0 < \beta < 1$, and hence the absolute value of the antivibration sensitivity Si in driving the second lens unit becomes smaller than 1 as indicated by the following equation. It is therefore theoretically impossible to increase the antivibration sensitivity.

$$|Si| = |1 - \beta| < 1$$

SUMMARY OF THE INVENTION

It is an object of the present invention to provide an observation optical system which has an objective optical system having a high antivibration sensitivity while ensuring a space for an image

inverting system, antivibration driving mechanism, and the like between the objective optical system and an eyepiece optical system and can obtain good optical performance with a lens arrangement constituted by a small number of lenses.

In order to achieve the above object, according to the present invention, there is provided an observation optical system including an objective optical part which forms an image of an object, an image inverting part which converts an image formed by the objective optical part into an erect image, and an eyepiece optical part which guides the erect image converted by the image inverting part to an observer, wherein the objective optical part has a first lens unit with a negative power and a second lens unit with a positive power arranged from an object side in the order named, and the second lens unit is movable in a direction that includes a component perpendicular to an optical axis to stabilize an image.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a sectional view showing an observation optical system according to numerical embodiment 1 in an embodiment of the present invention;

Fig. 2 is a sectional view showing an

observation optical system according to numerical embodiment 2 in the embodiment of the present invention;

Fig. 3 is a sectional view showing an observation optical system according to numerical embodiment 3 in the embodiment of the present invention;

Fig. 4 is a sectional view showing an observation optical system according to numerical embodiment 4 in the embodiment of the present invention;

Fig. 5 is a sectional view showing an observation optical system according to numerical embodiment 5 in the embodiment of the present invention;

Fig. 6 is a sectional view showing an observation optical system according to numerical embodiment 6 in the embodiment of the present invention;

Fig. 7 is an aberration diagram corresponding to the observation optical system according to numerical embodiment 1 in the embodiment of the present invention;

Fig. 8 is an aberration diagram corresponding to the observation optical system according to numerical embodiment 2 in the embodiment of the present invention;

Fig. 9 is an aberration diagram corresponding to the observation optical system according to numerical embodiment 3 in the embodiment of the present invention;

Fig. 10 is an aberration diagram corresponding to the observation optical system according to numerical embodiment 4 in the embodiment of the present invention;

Fig. 11 is an aberration diagram corresponding to the observation optical system according to numerical embodiment 5 in the embodiment of the present invention; and

Fig. 12 is an aberration diagram corresponding to the observation optical system according to numerical embodiment 6 in the embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figs. 1 to 6 show the arrangements of observation optical systems based on numerical embodiments 1 to 6 according to an embodiment of the present invention.

Referring to Figs. 1 to 6, a first lens unit 1 has a negative power (= reciprocal of focal length), and a second lens unit 2 has a positive power. A point 3 on an optical axis 5 indicated by the chain line in each drawing serves as a swing center when

the second lens unit 2 is driven for antivibration.

Note that an objective lens part is comprised of the first and second lens units 1 and 2. An image-erecting prism 4 is part of an image inverting part and formed by, for example, a Porro prism or Pechan roof prism. An eyepiece part 8 is comprised of a plurality of lenses. An observation optical system is comprised of the objective lens part, image inverting part, and eyepiece part. Reference numeral 6 denotes a pupil plane of an observer.

In this embodiment, as described above, the objective lens part is comprised of the first lens unit 1 having a negative power and the second lens unit 2 having a positive power which are sequentially arranged from the object side.

By forming an objective optical system having negative and positive lens units arranged from the object side in the order named in this manner, the total length of the objective optical system becomes longer than the focal length of the objective optical system. This makes it possible to ensure a space large enough to arrange an image inverting system such as an image inverting prism and the like, an antivibration driving mechanism, and the like between the objective optical system and the eyepiece optical system. In addition, since the magnification of the second lens unit is represented by $\beta < 0$, an

antivibration sensitivity Si is given by

$$|Si| = |1 - \beta| > 1$$

Therefore, this arrangement is more advantageous in obtaining a high antivibration sensitivity than an arrangement using an objective optical system having positive and negative lens units or positive and positive lens units from the object side in the order named.

In this embodiment, the first lens unit 1 is comprised of a positive lens 1a and negative lens 1b arranged from the object side in the order named.

The second lens unit 2 is formed by a single lens (positive lens) having a positive power.

In this embodiment, letting Fo be the focal length of the overall objective lens part, f1 be the focal length of the first lens unit 1, f2 be the focal length of the second lens unit 2, and D12 be the distance between the first lens unit 1 and the second lens unit 2, the first and second lens units 1 and 2 are designed to satisfy

$$0.1 \leqq -Fo/f1 \leqq 1.0 \qquad \ldots(1)$$

$$1.1 \leqq Fo/f2 \leqq 3.0 \qquad \ldots(2)$$

$$0.01 \leqq D12/Fo \leqq 0.2 \qquad \ldots(3)$$

Conditional expression (1) indicates the ratio between the focal length of the first lens unit 1 and the focal length of the overall objective lens part. If the power of the first lens unit 1 is reduced

below the lower limit of conditional expression (1), the effect of increasing the total length of the objective lens part and the effect of improving the antivibration effect are lost. If the power of the first lens unit 1 is increased to exceed the upper limit of conditional expression (1), it becomes difficult to correct aberrations such as spherical aberration and curvature of field, and the total length of the objective lens part becomes too long.

Conditional expression (2) indicates the ratio between the focal length of the second lens unit 2 and the focal length of the objective lens part. If the power of the second lens unit 2 is reduced below the lower limit of conditional expression (2), the effect of increasing the total length of the objective lens part and the effect of improving the antivibration effect are lost. If the power of the second lens unit 2 is increased to exceed the upper limit of conditional expression (2), it becomes difficult to correct aberrations such as spherical aberration and curvature of field. In addition, as in this embodiment, if the power of the second lens unit 2 formed by one positive lens is increased, since the thickness and weight of the lens increase, the power consumption for antivibration driving increases.

Conditional expression (3) is associated with the ratio between the focal length of the overall

objective lens part and the distance (air gap) between the first lens unit 1 and the second lens unit 2. If the first lens unit 1 is brought much close to the second lens unit 2 to exceed the lower limit of conditional expression (3), the space for antivibration driving becomes insufficient. This may cause interference between the two units. If the distance exceeds the upper limit, since a divergent light beam emerges from the first lens unit 1, the second lens unit 2 needs to have a large effective diameter accordingly. As a result, the power consumption for antivibration driving increases.

In the observation optical system according to this embodiment, the second lens unit 2 is swung/driven about the point 3 on the optical axis to prevent image blur due to so-called hand vibrations and the like in an observation device such as a binocular or telescope incorporating this observation optical system.

Letting Tc be the distance from the vertex of the object-side surface of the second lens unit 2 to the swing center (when the direction on the image surface side is a positive direction, and the direction on the object side is a negative direction), the position of the swing center 3 is set to satisfy

$$0.1 \leqq Tc/Fo \leqq 0.7 \qquad \ldots(4)$$

Conditional expression (4) is associated with

the position 3 of the swing center when the antivibration function is effected by swinging/driving the second lens unit 2 about the point 3 on the optical axis. By satisfying this condition, the effect of correcting the aberrations caused in antivibration operation, decentered coma and decentered curvature of field, in particular, can be obtained. In consideration of the swinging mechanism of the second lens unit 2, the swing center 3 is preferably located at a position that is closer to the image side than the objective lens part and closer to the object side than the image inverting part.

If the swing center 3 is brought close to the second lens unit 2 below the lower limit of conditional expression (4), decentered aberrations are excessively corrected. In addition, since the rotational angle required for driving increases, the antivibration mechanism becomes undesirably complicated. If the swing center 3 is separated from the second lens unit 2 beyond the upper limit, the aberration correcting effect decreases, and an effect corresponding to the driving mechanism cannot be obtained. In this case, the antivibration function is preferably effected by shifting the second lens unit 2 in a direction perpendicular to the optical axis rather than swinging the second lens unit 2 about a

remote swing center because the mechanism can be simplified.

In this embodiment, by determining the power arrangement of the objective optical system under the above conditions, excellent image performance and high antivibration sensitivity can be obtained while a space for the image inverting system and antivibration driving mechanism system is ensured.

In addition, in order to obtain high cost performance with a small number of components while maintaining high optical performance, each lens unit constituting the objective lens part is desired as follow in this embodiment.

(a) The first lens unit 1 is formed by arranging a positive lens with its convex surface facing the object side and a negative lens with its concave surface facing the image side from the objective side in the order named.

(b) The second lens unit 2 is formed by a positive lens having a strong convex surface facing the object side.

(c) The first lens unit 1 is formed by a cemented lens of positive and negative lenses.

With the arrangement of the first lens unit 1 in which the positive and negative lenses are arranged in the order named as in "(a)", the position of the principal point of the first lens unit 1 can be set

to be closer to the object side than the lens, the distance between the first and second lens units need not be unnecessarily large. In addition, in correcting aberrations in antivibration operation, since the lens surfaces of the respective lenses constituting the first lens unit 1 are substantially concentrically arranged with respect to the swing center of the second lens unit 2, the occurrence of coma due to antivibration operation and the like can be suppressed.

Furthermore, in optimally shaping the second lens unit 2 to locate the swing center 3 on the image side of the second lens unit 2 and the object side of the image inverting system, it is advantageous to shape the object-side surface of the positive lens into a surface close to concentric circles as in "(b)". If, however, the object-side surface of the second lens unit 2 is shaped into perfect concentric circles, the effect of moving an image for antivibration can only be obtained from the image-side surface. A balance needs to be achieved to ensure high sensitivity in antivibration operation while correcting aberrations.

By forming the first lens unit 1 using a cemented lens as in "(c)", the sensitivity in manufacturing the first lens unit 1 can be reduced.

The following are numerical embodiments. In

each numerical embodiment, let ri be the radius of curvature of the ith surface from the object side, di be the thickness or air gap of the ith optical member from the object side, and ni and νi be the refractive index and Abbe number, respectively, of the glass of the ith lens from the object side.

<Numerical Embodiment 1>

r1 = 40.057	d1 = 2.97	n1 = 1.51633	ν1 = 64.1
r2 = 58.056	d2 = 1.80	n2 = 1.67270	ν2 = 32.1
r3 = 34.647	d3 = 2.70		
r4 = 43.502	d4 = 3.13	n3 = 1.51633	ν3 = 64.1
r5 = -588.602	d5 = 53.40		
r6 = ∞	d6 = 16.00	n4 = 1.56883	ν4 = 56.4
r7 = ∞	d7 = 16.00	n5 = 1.56883	ν5 = 56.4
r8 = ∞	d8 = 16.00	n6 = 1.56883	ν6 = 56.4
r9 = ∞	d9 = 16.00	n7 = 1.56883	ν7 = 56.4
r10= ∞	d10= 3.69		
r11= -11.414	d11= 7.10	n8 = 1.69680	ν8 = 55.5
r12= -12.339	d12= 12.56		
r13= -45.932	d13= 1.62	n9 = 1.84666	ν9 = 23.8
r14= 19.645	d14= 8.07	n10= 1.71300	ν10= 53.9
r15= -16.788	d15= 0.20		
r16= 17.999	d16= 3.77	n11= 1.69680	ν11= 55.5
r17= 103.694	d17= 13.50		

rotation center Tc = 25 mm

<Numerical Embodiment 2>

r1 = 43.012	d1 = 2.97	n1 = 1.51633	ν 1 = 64.1
r2 = 62.298	d2 = 1.80	n2 = 1.67270	ν 2 = 32.1
r3 = 35.458	d3 = 2.70		
r4 = 42.466	d4 = 3.13	n3 = 1.51633	ν 3 = 64.1
r5 = -354.948	d5 = 52.34		
r6 = ∞	d6 = 16.00	n4 = 1.56883	ν 4 = 56.4
r7 = ∞	d7 = 16.00	n5 = 1.56883	ν 5 = 56.4
r8 = ∞	d8 = 16.00	n6 = 1.56883	ν 6 = 56.4
r9 = ∞	d9 = 16.00	n7 = 1.56883	ν 7 = 56.4
r10= ∞	d10= 3.71		
r11= -10.149	d11= 6.56	n8 = 1.71300	ν 8 = 53.9
r12= -10.784	d12= 6.72		
r13= -15.949	d13= 2.52	n9 = 1.84666	ν 9 = 23.8
r14= 20.741	d14= 8.98	n10= 1.71300	ν 10= 53.9
r15= -13.426	d15= 7.18		
r16= 19.745	d16= 3.39	n11= 1.69680	ν 11= 55.5
r17= 1815.623	d17= 13.50		

rotation center Tc = 25 mm

<Numerical Embodiment 3>

r1 = 47.819	d1 = 3.30	n1 = 1.51633	ν 1 = 64.1
r2 = 71.930	d2 = 2.00	n2 = 1.67270	ν 2 = 32.1
r3 = 39.989	d3 = 3.00		
r4 = 49.519	d4 = 2.90	n3 = 1.51633	ν 3 = 64.1
r5 = -339.560	d5 = 58.19		
r6 = ∞	d6 = 17.50	n4 = 1.56883	ν 4 = 56.4
r7 = ∞	d7 = 20.25	n5 = 1.56883	ν 5 = 56.4
r8 = ∞	d8 = 20.25	n6 = 1.56883	ν 6 = 56.4
r9 = ∞	d9 = 17.50	n7 = 1.56883	ν 7 = 56.4
r10= ∞	d10= 15.02		
r11= -16.613	d11= 1.20	n8 = 1.84666	ν 8 = 23.8
r12= 20.236	d12= 8.31	n9 = 1.77250	ν 9 = 49.6
r13= -16.450	d13= 1.00		
r14= 30.821	d14= 4.09	n10= 1.77250	ν 10= 49.6
r15= -138.382	d15= 4.51		
r16= 17.191	d16= 2.70	n11= 1.77250	ν 11= 49.6
r17= 26.000	d17= 14.50		

rotation center Tc = 20 mm

<Numerical Embodiment 4>

r1 = 42.034	d1 = 2.75	n1 = 1.51633	ν 1 = 64.1
r2 = 62.379	d2 = 1.67	n2 = 1.67270	ν 2 = 32.1
r3 = 34.159	d3 = 2.50		
r4 = 40.916	d4 = 2.90	n3 = 1.51633	ν 3 = 64.1
r5 = -251.238	d5 = 52.41		
r6 = ∞	d6 = 16.00	n4 = 1.56883	ν 4 = 56.4
r7 = ∞	d7 = 16.00	n5 = 1.56883	ν 5 = 56.4
r8 = ∞	d8 = 16.00	n6 = 1.56883	ν 6 = 56.4
r9 = ∞	d9 = 16.00	n7 = 1.56883	ν 7 = 56.4
r10= ∞	d10= 6.83		
r11= -16.782	d11= 2.61	n8 = 1.80518	ν 8 = 25.4
r12= 15.534	d12= 6.65	n9 = 1.71300	ν 9 = 53.9
r13= -15.767	d13= 0.50		
r14= -102.738	d14= 2.00	n10= 1.71300	ν 10= 53.9
r15= -31.180	d15= 0.60		
r16= 18.000	d16= 18.68	n11= 1.77250	ν 11= 49.6

rotation center Tc = 30 mm

<Numerical Embodiment 5>

r1 = 39.918	d1 = 2.75	n1 = 1.51633	ν 1 = 64.1
r2 = 65.558	d2 = 1.67	n2 = 1.67270	ν 2 = 32.1
r3 = 35.165	d3 = 2.50		
r4 = 40.687	d4 = 2.90	n3 = 1.51633	ν 3 = 64.1
r5 = -259.733	d5 = 52.10		
r6 = ∞	d6 = 16.00	n4 = 1.56883	ν 4 = 56.4
r7 = ∞	d7 = 16.00	n5 = 1.56883	ν 5 = 56.4
r8 = ∞	d8 = 16.00	n6 = 1.56883	ν 6 = 56.4
r9 = ∞	d9 = 16.00	n7 = 1.56883	ν 7 = 56.4
r10= ∞	d10= 7.74		
r11= -7.683	d11= 1.00	n8 = 1.84666	ν 8 = 23.8
r12= 140.592	d12= 6.35	n9 = 1.60311	ν 9 = 60.6
r13= -10.156	d13= 0.50		
r14= -67.812	d14= 4.10	n10= 1.71300	ν 10= 53.9
r15= -22.404	d15= 0.33		
r16= 27.007	d16= 3.86	n11= 1.69680	ν 11= 55.5
r17= -358.343	d17= 0.17		
r18= 15.958	d18= 7.46	n12= 1.77250	ν 12= 49.6
r19= 15.000	d19= 14.50		

rotation center Tc = 25 mm

<Numerical Embodiment 6>

r1 = 47.819	d1 = 3.30	n1 = 1.51633	ν 1 = 64.1
r2 = 71.930	d2 = 2.00	n2 = 1.67270	ν 2 = 32.1
r3 = 39.989	d3 = 3.00		
r4 = 49.519	d4 = 2.90	n3 = 1.51633	ν 3 = 64.1
r5 = -339.560	d5 = 58.19		
r6 = ∞	d6 = 17.50	n4 = 1.56883	ν 4 = 56.4
r7 = ∞	d7 = 20.25	n5 = 1.56883	ν 5 = 56.4
r8 = ∞	d8 = 20.25	n6 = 1.56883	ν 6 = 56.4
r9 = ∞	d9 = 17.50	n7 = 1.56883	ν 7 = 56.4
r10= ∞	d10= 14.76		
r11= -10.807	d11= 1.20	n8 = 1.84666	ν 8 = 23.8
r12= 22.083	d12= 8.17	n9 = 1.77250	ν 9 = 49.6
r13= -14.798	d13= 0.60		
r14= 118.961	d14= 4.56	n10= 1.71300	ν 10= 53.9
r15= -37.367	d15= 0.50		
r16= 21.371	d16= 3.70	n11= 1.69680	ν 11= 55.5
r17= 54.095	d17= 2.65		
r18= 13.923	d18= 2.70	n12= 1.71300	ν 12= 53.9
r19= 13.544	d19= 14.50		

rotation center Tc = 50 mm

Table 1 shows the relationship between the respective conditional expressions described above and the numerical values in the respective numerical embodiments.

<Table 1>

	Embodiment 1	Embodiment 2	Embodiment 3	Embodiment 4	Embodiment 5	Embodiment 6
-Fo/f1	0.335	0.401	0.390	0.422	0.424	0.390
Fo/f2	1.381	1.441	1.430	1.459	1.463	1.430
D12/Fo	0.025	0.025	0.025	0.025	0.025	0.025
Tc/Fo	0.230	0.236	0.167	0.301	0.250	-

Figs. 7 to 12 are aberration diagrams of the observation optical systems according to numerical

embodiments 1 to 6.

This embodiment has exemplified the case where the second lens unit 2 is swung about a point on the optical axis 5 to effect the antivibration function. However, the present invention can also be applied to a case where the second lens unit 2 is shifted/driven in a direction perpendicular to the optical axis 5 to effect the antivibration function. The arrangement based on numerical embodiment 6 shown in Fig. 6, in particular, is designed to realize excellent image performance and antivibration function in either of the driving mechanisms.